

COLD DARK MATTER AND PRIMORDIAL SUPERHEAVY PARTICLES

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The hypothesis that cold dark matter consists of primordial superheavy particles, the decay of short lifetime component of which led to the observable mass of matter while long living component survived up to modern times manifesting its presence in high energetic cosmic rays particles is investigated.

Keywords: particle creation; dark matter; early universe.

1 Introduction

In this paper we shall give some new evaluation of our proposal made in papers [1], [2] according to which experimental observations of high energetic cosmic particles with the energy higher than the Greizen–Zatsepin–Kuzmin limit [3] are interpreted as decays of superheavy particles forming the cold dark matter in the vicinity of our Galaxy. As it is known [4] creation of superheavy particles with the mass of the order of the Grand Unification scale with the subsequent decays of its short living component on quarks and leptons with baryon charge and CP -nonconservation can lead to explanation of the observable matter. In Refs. [1], [2] the idea that long living component of primordial superheavy particles can survive up to modern time in the form of cold dark matter was discussed and some rough estimates of its density were made.

Different experimental collaborations — AGASA [5], Haverah Park [6], Fly Eye [7], Yakutsk [8] observe in cosmic rays events corresponding to the energy higher than 10^{20} eV. According to the standard theory of cosmic rays if the most energetic particles come from the other galaxies accelerated by the magnetic fields, protons and neutrons must interact during the flight with photons of the primordial background radiation. This radiation in the reference frame of cosmic particles moving with big velocity interacts so that pions are created. So cosmic particles must be decelerated and the Greizen–Zatsepin–Kuzmin cutoff of the high energy tail of the spectrum of cosmic rays evaluated as 10^{20} eV is predicted.

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Many different hypotheses to explain the observable events were presented, one of them being the existence of superheavy massive neutral particles of cold dark matter.

Here we shall discuss just this hypothesis. The reason for this is to consider these particles as relics of creation of particles in the early Friedmann Universe which resulted in the origination of visible matter, i.e. in the Eddington number of protons and leptons. Strong gravitational field of the early expanding Friedmann Universe created from vacuum pairs of some X and anti- X particles of the mass of the order of the Grand Unification order at the Compton time from the singularity. Due to nonconservation of the baryon charge in some model of Grand Unification which is not specified in our paper these particles being created by gravity with the definite baryon charge then decay similarly to neutral K -mesons as some short living and long living components. Our idea is to look for such values of the parameters of the model which can lead to the cosmological life-time of the long living component so that it can exist today while the short living component decayed close to the Grand Unification time. Our calculations of particle creation in the early Friedmann Universe [9] give the Eddington number of superheavy particles created by gravity. If these particles did not decay they would lead to a quick collapse of the closed Friedmann Universe or to a totally different from the observed open or quasi-Euclidean Universe. So these particles must decay on light particles (here we suppose the energetic desert hypothesis). But these decays are different for short living and long living components. Short living components decay in the time when the Grand Unification symmetry is not broken while the long living component survives the symmetry breaking. However the number of long living particles is not equal to the number of created superheavy particles because similar to the behaviour of neutral K -mesons created by strong interactions and decaying through weak interactions if long living particles decay not in vacuum but in the substance with nonzero baryon charge they will be converted in the short living particles and will quickly decay. This process will be dependent on the density of particles. This density is high in the early Universe and is small at the modern era. Now proceed to the model.

2 Model and Numerical Estimates

At first suppose superheavy X -particles to be scalar particles. Total number of massive scalar particles created in Friedmann radiation dominated Universe (scale factor $a(t) = a_0 t^{1/2}$) inside the horizon is as it is known [9]:

$$N = n^{(0)}(t) a^3(t) = b^{(0)} M^{3/2} a_0^3, \quad (1)$$

where $b^{(0)} \approx 5.3 \cdot 10^{-4}$ ($N \sim 10^{80}$ for $M \sim 10^{15}$ Gev, see Ref. [9]). For the time $t \gg M^{-1}$ there is an era of going from the radiation dominated model to the dust model of superheavy particles

$$t_X \approx \left(\frac{3}{64\pi b^{(0)}} \right)^2 \left(\frac{M_{Pl}}{M} \right)^4 \frac{1}{M}. \quad (2)$$

If $M \sim 10^{14}$ Gev, $t_X \sim 10^{-15}$ sec, if $M \sim 10^{13}$ Gev — $t_X \sim 10^{-10}$ sec. So the life time of short living X -mesons must be smaller then t_X .

Let us define d — the permitted part of long living X -mesons — from the condition: on the moment of recombination t_{rec} in the observable Universe one has $d \varepsilon_X(t_{rec}) = \varepsilon_{crit}(t_{rec})$, where ε_{crit} is the critical density for the time t_{rec} . It leads to

$$d = \frac{3}{64\pi b^{(0)}} \left(\frac{M_{Pl}}{M} \right)^2 \frac{1}{\sqrt{M t_{rec}}}. \quad (3)$$

For $M = 10^{13} - 10^{14}$ Gev one has $d \approx 10^{-12} - 10^{-14}$. Using the estimate for the velocity of change of the concentration of long living superheavy particles [10] $|\dot{n}_x| \sim 10^{-42} \text{ cm}^{-3} \text{ sec}^{-1}$, and taking the life time τ_l of long living particles as $2 \cdot 10^{22}$ sec, we obtain concentration $n_X \approx 2 \cdot 10^{-20} \text{ cm}^{-3}$ at the modern epoch, corresponding to the critical density for $M = 10^{14}$ Gev.

Now let us construct the toy model which can give: a) short living X -mesons decay in time $\tau_q < 10^{-15}$ sec, (more wishful is $\tau_q \sim 10^{-38} - 10^{-35}$ sec), long living mesons decay with $\tau_l > t_U \approx 10^{18}$ sec (t_U is the age of the Universe), b) one has small $d \sim 10^{-14} - 10^{-12}$ part of long living X -mesons, forming the dark matter.

Baryon charge nonconservation with CP -nonconservation in full analogy with the K^0 -meson theory with nonconserved hypercharge and CP -nonconservation leads to the effective Hamiltonian of the decaying X, \bar{X} - mesons with nonhermitean matrix.

For the matrix of the effective Hamiltonian $H = \{H_{ij}\}$, $i, j = 1, 2$ let $H_{11} = H_{22}$ due to CPT -invariance. Denote $\varepsilon = (\sqrt{H_{12}} - \sqrt{H_{21}}) / (\sqrt{H_{12}} + \sqrt{H_{21}})$. The eigenvalues $\lambda_{1,2}$ and eigenvectors $|\Psi_{1,2}\rangle$ of matrix H are

$$\lambda_{1,2} = H_{11} \pm \frac{H_{12} + H_{21}}{2} \frac{1 - \varepsilon^2}{1 + \varepsilon^2}, \quad (4)$$

$$|\Psi_{1,2}\rangle = \frac{1}{\sqrt{2(1+|\varepsilon|^2)}} [(1+\varepsilon)|1\rangle \pm (1-\varepsilon)|2\rangle]. \quad (5)$$

In particular

$$H = \begin{pmatrix} E - \frac{i}{4}(\tau_q^{-1} + \tau_l^{-1}) & \frac{1+\varepsilon}{1-\varepsilon} [A - \frac{i}{4}(\tau_q^{-1} - \tau_l^{-1})] \\ \frac{1-\varepsilon}{1+\varepsilon} [A - \frac{i}{4}(\tau_q^{-1} - \tau_l^{-1})] & E - \frac{i}{4}(\tau_q^{-1} + \tau_l^{-1}) \end{pmatrix}. \quad (6)$$

Then the state $|\Psi_1\rangle$ describes short living particles with the life time τ_q and mass $E + A$. The state $|\Psi_2\rangle$ is the state of long living particles with life time τ_l and mass $E - A$. Here A is the arbitrary parameter $-E < A < E$ and it can be zero, $E = M$.

In analogy with the K -meson system let us take into account transformations of the long living component into the short living one due to the presence of baryon substance created by decays of the short living particles. This process surely will depend on the density of the substance and instead of the rough estimate in our previous paper [1] leading to some strong restrictions on the

parameters of the CP -violation here one obtains more realistic model. Let us investigate the model with the interaction which in the basis $|1\rangle, |2\rangle$ is described by the matrix

$$H^d = \begin{pmatrix} 0 & 0 \\ 0 & -i\gamma \end{pmatrix}. \quad (7)$$

Then

$$\langle \Psi_1 | H^d | \Psi_2 \rangle = \langle \Psi_2 | H^d | \Psi_1 \rangle = i \frac{\gamma}{2} \frac{|1 - \varepsilon|^2}{1 + |\varepsilon|^2}. \quad (8)$$

which is different from the analogous expression in our paper [1] by the factor dependent on γ . The eigenvalues of the Hamiltonian $H + H^d$ are

$$\lambda_{1,2}^d = E - \frac{i}{4} (\tau_q^{-1} + \tau_l^{-1}) - i \frac{\gamma}{2} \pm \sqrt{\left(A - \frac{i}{4} (\tau_q^{-1} - \tau_l^{-1}) \right)^2 - \frac{\gamma^2}{4}}. \quad (9)$$

In case when $\gamma \ll \tau_q^{-1}$ for the long living component one obtains

$$\lambda_2^d \approx E - A - \frac{i}{2} \tau_l^{-1} - i \frac{\gamma}{2}, \quad (10)$$

$$\|\Psi_2(t)\|^2 = \|\Psi_2(t_0)\|^2 \exp \left[\frac{t_0 - t}{\tau_l} - \int_{t_0}^t \gamma(t) dt \right]. \quad (11)$$

The parameter γ , describing the interaction with the substance of the baryon medium, is evidently dependent on its state and concentration of particles in it. For approximate evaluations take this parameter as proportional to the concentration of particles: $\gamma = \alpha n^{(0)}(t)$. Putting $\tau_l = 2 \cdot 10^{22}$ sec, $t \leq t_U$, $a(t) = a_0 \sqrt{t}$ by (1) one obtains

$$\|\Psi_2(t)\|^2 = \|\Psi_2(t_0)\|^2 \exp \left[\alpha 2b^{(0)} M^{3/2} \left(\frac{1}{\sqrt{t}} - \frac{1}{\sqrt{t_0}} \right) \right]. \quad (12)$$

So the decay of the long living component due to this mechanism takes place close to the time t_0 which can be taken as equal to the Compton one for X -particles $t_0 \approx t_C = 1/M$. If d – is the part of long living particles surviving up to the time t ($t_U \geq t \gg t_C$) then from (12) one obtains the evaluation for the parameter α

$$\alpha = -\ln d / (2b^{(0)} M^2). \quad (13)$$

For $M = 10^{14}$ GeV and $d = 10^{-14}$ one obtains $\alpha \approx 10^{-41} \text{sm}^3/\text{sec}$. If $\tau_q \sim 10^{-38} - 10^{-35}$ sec then the condition $\gamma(t) \ll \tau_q^{-1}$ used in Eq. (10) is valid for $t > t_C$. For this the value α we have $\gamma(t_U) \approx 10^{-47} \text{sec}^{-1} \ll \tau_l^{-1}$. So one can neglect this mechanism for the decay of the long living component of X -particles for the modern epoch while for early universe at $t_0 \approx t_C$ it was important. There is no special restriction on the parameter of CP -breaking in this model.

We supposed for simplicity the superheavy particles to be scalars. However one can consider them to be fermions. The superheavy fermions are used, for example, in some models of neutrino mass generation (the *see-saw* mechanism) in Grand Unification theories [11], [12]. Our scheme will be the same for the fermions. New experiments on high energetic particles in cosmic rays surely will give us more information on their structure and origin.

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